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# Use of an On-Line Computer in Neutron Time-of-Flight Measurements

U.S. DEPARTMENT OF COMMERCE  
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## **Use of an On-Line Computer in Neutron Time-of-Flight Measurements**

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This paper describes the on-line data handling system at the NBS Electron Linear Accelerator facility as it is used for measuring neutron total cross sections by time-of-flight techniques.

Key Words: Data handling system; interruptable computer; neutron time-of-flight; neutron total cross sections; Program Selector Board; on-line computer.

## 1. Introduction

In the last few years, the use of on-line computers for gathering data in nuclear physics experiments has become commonplace. There are several reviews [1,2]<sup>1</sup> on the general functions an on-line computer system can perform. The general philosophy of the on-line computer system at the NBS Electron Linear Accelerator (linac) facility has been described previously. [3-5] A detailed explanation of one of the experimental programs (Neutron Time-of-Flight) which routinely uses this computer will be given in this paper. The paper will describe what signals from experimental equipment are sent to the computer, how the computer uses this information to make decisions depending on the signals, and what are the limits and capabilities for this on-line system.

The first part of the paper will describe the physical characteristics of the on-line computer and its associated hardware. The second section will describe the Neutron Time-of-Flight project and its use of the computer. The appendix will be more specific and will describe computer programs used to gather and monitor the experimental quantities.

## 2. Computer Characteristics

The on-line computer used at the NBS linac is an SDS-920. It has a 16K word memory, each word having 24 bits. The machine cycle time is 8  $\mu$ s with a typical machine language instruction of 2 or 3 cycles. The registers available to the programmer are the main accumulator, an extended accumulator for the least significant portion of double length words, an index register, and a 14 bit register containing the address of the current instruction.

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<sup>1</sup>Figures in brackets indicate literature references at the end of this paper.

The SDS-920 is a real time computer with interrupt capability. The 80 levels of priority interrupts have led to a modular concept of both hardware and software in a system called ROMEO [3-5] (Real time, On-line, Modular, Experimental, Operator). Since I/O operations in the FORTRAN compiler available for this computer are not interruptable, all programs for the ROMEO system are written in machine language.

There are two types of machine language programs, Interrupt and Board. Both types of programs may have a region of memory following the main body of the program which is a data field. By means of the Program Selector Board (PSB) any Board program (referred to as the subject program) may operate on the data field of any program (referred to as the object program). Further discussion of Board programs necessitates a description of the Program Selector Board, and hence will be postponed to later in this section.

Interrupt Programs are used to record experimental data as it is presented to the computer. The order in which the Interrupt programs are performed is determined by the value of the linkage table associated with the particular Interrupt program. The Interrupt programs used in Time-of-Flight experiments are given in Table 1. The highest level program is indicated by 0. Increasing value of the linkage table means lower priority for the Interrupt program.

The interrupt capability of the computer is accomplished by testing for an active signal on the interrupt interface after each machine language instruction. If the new interrupt is of a higher priority than the one associated with the program in operation, the higher level program will be performed before the lower level program is completed by having the computer branch to the location in memory (given in the linkage table) of the higher level program. If the computer is not carrying out a program, it returns to a "wait loop" (a set of instructions branching back to themselves) and awaits the next interrupt.

The modular concept of programming has proved very useful. It prevents duplication of effort among the various experimental groups using the computer. Modular programs, as opposed to one program which would perform the entire experiment, are of use when new equipment is added, as only programs for this new equipment must be written, instead of rewriting one long program. A compromise between loading all of the modular programs each time the experiment is performed and one long program to carry out the experiment is made by loading the programs, and then making a dump of the memory with a self-loading bootstrap. The master tape thus produced is then loaded at the beginning of each experiment. If there are any new programs to be loaded, or any priorities to be changed, this can be done at this time.

The computer hardware built at NBS also has a modular concept. The experimental hardware includes: 4 Program Selector Boards, 16 Analog to Digital Converters (each with selectable number of channels up to 512), 4 scalars, 8 Digital Volt Meters, 3 Digital Register Units (24 line



Table 1

Interrupt Programs

00 MT Master Timer  
 01 RT Increment Data  
 02 RT Increment Data  
 03 RT Increment Data  
 04 RT Increment Data  
 05 RT Increment Data  
 06 TC 4100 Time Channels  
 07 SR Start Rate

10 SQ Coincidence Rate  
 11 TN Tube Noise 1  
 12 TM Tube Noise 2  
 13 TL Tube Noise 3  
 14  
 15  
 16  
 17

20 RT Increment Data  
 21 RT Increment Data  
 22 RT Increment Data  
 23 RT Increment Data  
 24 RT Increment Data  
 25  
 26  
 27

30 HP PBS 4-1  
 31 HD PBS 1-1  
 32 HQ PBS 4-2  
 33 HE PBS  
 34  
 35  
 36  
 37

50 HR PBS 4-3  
 51  
 52  
 53 HF PBS 1-3  
 54 HS PBS 4-4  
 55 HG PBS 1-4  
 56  
 57

117 HC Delete

All linkage locations not explicitly given are loaded with Increment Data (RT) to insure that all interrupt levels have a program associated with them.

Table 2

## Board Programs

|    |    |                                |    |    |                            |
|----|----|--------------------------------|----|----|----------------------------|
| 00 | 10 | Zero Word                      | 40 | RG | Ratio-Y-Buf.               |
| 01 | LB | Clear                          | 41 |    |                            |
| 02 | YL | Type Line of Data-Y-Buf.       | 42 |    |                            |
| 03 | YC | Type 4 Carriage Returns Y-Buf. | 43 |    |                            |
| 04 | YE | Type 4 Carriage Returns W-Buf. | 44 |    |                            |
| 05 | RP | General I7 Punch               | 45 |    |                            |
| 06 |    |                                | 46 | IA | Scaler Save                |
| 07 | RA | Paper Taper                    | 47 | IA | Scaler Save                |
| 10 | ID | Type Data Message-W-Buf.       | 50 | QB | Read Residuals             |
| 11 | YD | Type Data Message-W-Buf.       | 51 | QC | Read Residuals             |
| 12 | TL | Type Line of Data-W-Buf.       | 52 | QD | Read Residuals             |
| 13 | TW | List Sequencer                 | 53 | EU | Clear Scaler, 2, 3, 4      |
| 14 | 10 | Decimal Type In-W-Buf.         | 54 | LX | List Collector             |
| 15 | IE | Store Message                  | 55 | NR | Run Number Increment       |
| 16 | IC | Load Data Field-W-Buf.         | 56 | ON | Group Enable 6 On          |
| 17 |    |                                | 57 | OF | Group Enable 6 Off         |
| 20 |    |                                | 60 | SD | Scope (Counting Room 3)    |
| 21 |    |                                | 61 | MB | 64 Word Simple Operations  |
| 22 | RT | Paper Tiger                    | 62 | MD | 256 Word Simple Operations |
| 23 |    |                                | 63 | LI | Smooth                     |
| 24 | SA | Scope (Control Room)           | 64 | KM | 4100 Block Sequester       |
| 25 | CZ | Sum                            | 65 | KN | 256 Block Sequester        |
| 26 | KO | One Word Sequester (Scaler 3)  | 66 | KO | One Word Sequester (P2)    |
| 27 | KO | One Word Sequester (Scaler 4)  | 67 | KO | One Word Sequester (SEM)   |
| 30 | CX | Ratio Loader                   | 70 |    |                            |
| 31 | CX | Ratio Loader                   | 71 | HD | List Loader (1-1)          |
| 32 | CX | Ratio Loader                   | 72 | HP | List Loader (4-1)          |
| 33 | CX | Ratio Loader                   | 73 | HF | Sequencer (1-4, 40)        |
| 34 | CX | Ratio Loader                   | 74 | HK | Sequencer (4-2, 77)        |
| 35 | CX | Ratio Loader                   | 75 | HR | Sequencer (4-4, 77)        |
| 36 | IA | Scaler Save                    | 76 | HC | Linkage Lister             |
| 37 | IA | Scaler Save                    | 77 | HA | Loader                     |

parallel input), and a 60 Hz clock. Other equipment interfaced to the computer includes a Time Interval Meter (TIM), and a high precision digital voltage meter. The input/output hardware includes: 4 oscilloscope displays, an x-y plotter, a paper tape punch, a photoreader, a light pen, a typewriter and a teletypewriter.

The digital output from the experimental hardware is transferred to the computer via the Multiplex Register Unit (MRU). When the point in an interrupt program is reached where the information from a piece of equipment is needed, the instruction "Energize Output" (EOM) is used to bring this information into the MRU. The instruction "Parallel Input" (PIN) will then bring the contents of the MRU into computer memory. The address portion of the EOM instruction determines which piece of equipment is interrogated. In addition to interrogating equipment, the EOM signals can be used to initiate another program, increment a stepping motor, open a relay, etc.

All peripheral counting equipment used in the time-of-flight experiments can be turned on or off simultaneously by means of the Group Enable (GE) by gating the device with the GE signal.

The manipulation of the data in the Interrupt data field is accomplished by Board programs. The Board programs used in the Time-of-Flight experiments are given in Table 2. Similar to Interrupt programs, the means of entering Board programs in the computer memory is through a linkage table. For Board programs, however, the value of the linkage location is used only as an identifier, and does not establish a program priority. Since Board programs may operate on any data field, the device which informs the computer which Board program to perform, and on which data field that Board program should operate, is the Program Selector Board.

A typical PSB is shown in figure 1. Each Program Selector Board contains 4 sets of thumbdials used to manually set up a control word which the computer is programmed to read in upon command. The maximum configuration of a set of thumbdials is 17 77 1177 77. The 10 dials divide up the 24 bit word of the computer with a 7 on a dial occupying 3 bits of the word and a 1 on a dial occupying 1 bit. Labeling the dials from 1 to 10, the computer word is divided as indicated: Dials 9, 10 correspond to the octal value of the Board linkage table location of the subject program, dials 6-8 give the octal linkage location of the object program, dial 5 indicates whether the object program is a Board program (0) or an Interrupt program (1), dials 1-4 are used to control internal options in the subject programs. After setting the thumbdial to the appropriate values, the Board program is initiated by the SINGLE CYCLE button, REPEAT CYCLE switch (60 Hz) or the EXT CYCLE input. This initiates an Interrupt program which reads the control word on the set of thumbdials and then makes certain logical checks. These logical checks include whether the WBuffer or YBuffer is in use, if the subject program is loaded, if the object program is loaded, and if the subject program is currently in use. If a check should fail, the REJECT light and appropriate function light are lit. If the logical tests are passed,

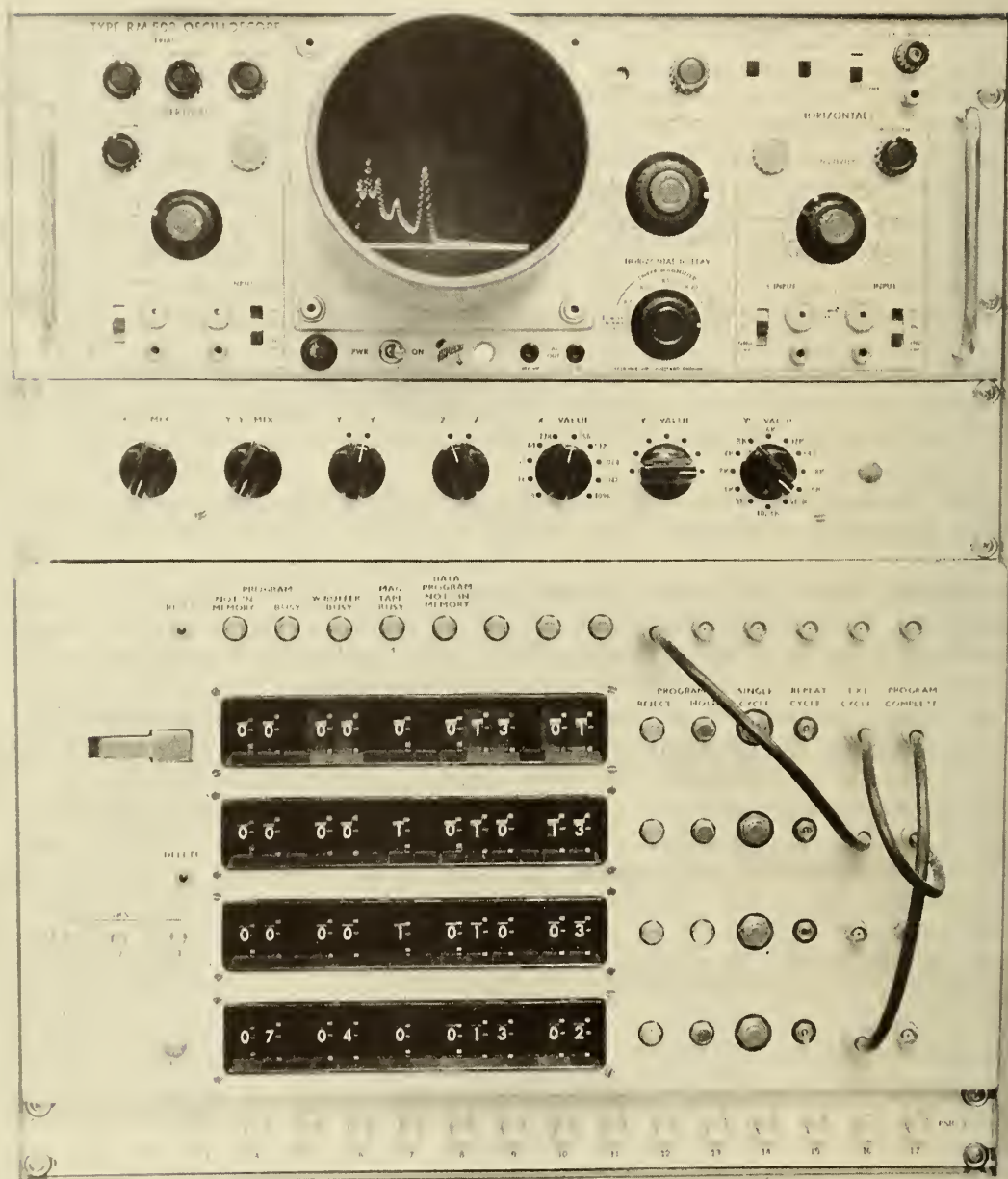


Figure 1. A typical remote station to the computer showing the four sets of thumbdials on the Program Board Selectors used to call Board Program (see text).



the interrupt control program branches to the Board program and executes it. When the Board program is completed, the interrupt control program sends an EOM signal over the PROGRAM COMPLETE BNC. This in turn can be fed into the EXT CYCLE connection to initiate another Board program. On the PSB are 3 switches (labeled SKS) which can be used to control yes/no options within the Board program.

### 3. Experimental Arrangement

The Neutron Time-of-Flight group at the NBS electron linear accelerator performs two major types of experiments, the measurement of photo-neutron cross sections and the measurement of neutron total cross sections. [6-8] In both cases a neutron spectrum produced by the 2 nano-second linac beam pulse is recorded. In the photoneutron experiments, the linac electron beam passes through a thin radiator producing a bremsstrahlung pulse which strikes the target under investigation. In the total cross section measurements, the electron beam is allowed to strike a target directly. In this case the neutron spectrum produced furnishes the "open" spectrum necessary for making a transmission measurement. The "sample in" spectrum is obtained by inserting the element to be measured in the neutron flight path. When corrections have been made for background and dead-time effects, the ratio of the sample-in to sample-out counts in channel  $i$  is the transmission,  $T_i$ , of the element, in the  $i$ th channel. This is related to the total cross section,  $\sigma_i$ , by

$$T_i = e^{-n\sigma_i} \quad (1)$$

where  $n$  is the atoms per square cm of the sample.

Although the results of these two experiments are quite different, all of the electronic equipment, and most of the on-line computer programs, can be used for either measurement. To date, only survey work has been done on photoneutron experiments, and hence the remainder of the paper will deal explicitly with the total cross section measurements.

The neutron energy range of interest for these measurements extends from about 500 keV to 15 MeV. Two events occur when the electron beam strikes the neutron target: neutrons are produced and an intense beam of gamma rays, the gamma flash, is produced. The energy of the neutrons is determined by the difference in time between the start and stop signals. The start signal is provided by the signal induced in a phototube by the gamma flash. The neutrons travel over an evacuated, collimated, 40 meter flight path and are detected by a liquid scintillator. The light produced by the proton recoil in the scintillator is detected by three photomultiplier tubes. The coincident output (to eliminate tube noise) provides the stop signal.

The major piece of equipment for a time-of-flight experiment is the instrument measuring the time between the start and stop signals. For these measurements a Time Interval Meter (TIM) digitally measures this difference in nanosecond steps or channels. This digital output of the

TIM (total number of nanoseconds) is recorded in a 4096 word data field of an interrupt program in the computer.

Converting eq. (1) to the experimental quantities measured, the neutron total cross section, in barns, for the Ith nanosecond time channel is

$$\sigma(I) = [\ln(C_{in}(I)/N C_{out}(I))]/n \quad (2)$$

where  $C_{in}(I)$  is the number of counts in channel I of the sample in spectrum,  $C_{out}(I)$  is the number of counts in channel I of the sample out spectrum,  $N$  is a normalization factor for different amounts of total electron beam charge between the sample in and sample out runs, and  $n$  is the atoms per barn of the sample.

If the cross section as a function of energy rather than time is desired, the neutron kinetic energy associated with the Ith time channel is given by the relativistic expression

$$E(I) = 939.55 \left[ \left( \frac{1}{1 - [(L/c)/T(I)]} \right)^{\frac{1}{2}} - 1 \right] \quad (3)$$

where, in appropriate units,  $L$  is the flight path length,  $c$  is the speed of light, and  $T(I)$  is the time-of-flight of the neutron. For the one nanosecond channels of the TIM, and by recording the gamma flash with the stop detector and observing in which TIM channel it occurred (GFC), and knowing the time in nanoseconds it takes light to travel over the flight path ( $L/c$ ), the time-of-flight can be expressed in terms of any TIM channel I by

$$T(I) = (L/c) - GFC + I \quad (4)$$

Figure 2 is a block diagram of the equipment used in neutron total cross section measurements. The major signals recorded by the computer are shown. The computer input signals are indicated by I and the level of the interrupt program associated with the signal by the subscript. These subscripts, and all other numbers referring directly to the computer, or to computer programs, are in base 8 unless stated otherwise. The slow electronics necessary to send logic signals to the computer are not shown in figure 2.

There are three main methods of monitoring the linac beam current. First the beam passes through a Secondary Emission Monitor (SEM) mounted in the beam handling system. The output of the SEM, which is proportional to the amount of charge in each beam pulse, is recorded by a current integrator. The gamma flash produced by the electron pulse from the linac when it strikes the neutron target is monitored by an NBS P2 ionization chamber. [9] The output of the P2, proportional to the energy in the beam passing through the neutron target, is also recorded by a current integrator. The integrator has a meter for reading the average current,

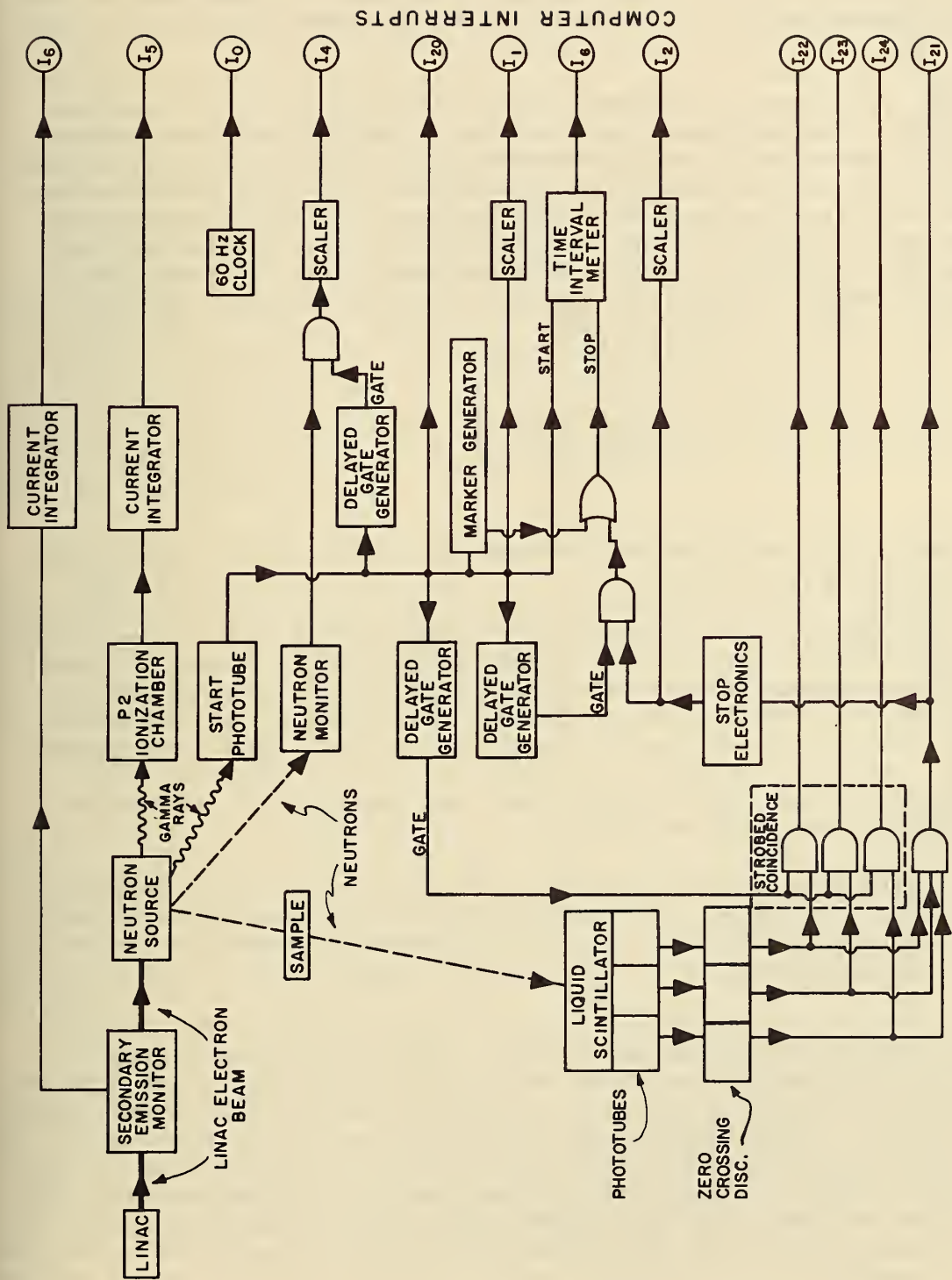


Figure 2. Block diagram of equipment used for measuring neutron total cross sections by time-of-flight techniques.



and has a pulsed output, the rate of which is proportional to the meter reading. The output of the integrator is recorded by the computer. The third monitor is a small liquid scintillator mounted in the room containing the neutron target and measures the average number of neutrons produced.

The total number of neutrons counted by the stop detector is also monitored. The total number of neutrons counted will be less than the sum of the neutrons in the spectrum due to the fact that the TIM can only count one neutron per linac pulse. This means there is a dead time correction which must be applied to both the sample in and the sample out spectra due to this one count per burst limitation. If  $s$  is the total number of start pulses, and  $O_i$  is the observed number of counts in channel  $i$ , then the number of dead time corrected counts in channel  $i$ ,  $C_i$ , is

$$C_i = \frac{O_i}{1 - \left[ \frac{O_i}{2s} + \sum_{j=1}^{i-1} \frac{O_j}{s} \right]} \quad (5)$$

These dead time corrected counts should be used in calculating the cross section given in eq. (2).

The highest priority program is one which counts 60 Hz pulses during the entire time GE is on, i.e., as long as data are being taken. After this program determines that 20 minutes have elapsed, it sends an EOM signal which in turn initiates a program which types out the ratios of SEM/P2 counts, total neutron/P2 counts and total neutron/neutron monitor counts. These ratios provide a running check on the stability of the experiment. If they are not consistent, the experimenter (rather than the computer) can stop the run.

For the remainder of the tests performed by the computer monitoring experimental conditions, the computer automatically terminates the run if the test fails. The experimenter is informed by having one of the spare lights on the PSB lit indicating which test failed.

In addition to providing a time zero signal for the TIM, the start signal performs several other functions. The total number of start pulses are counted for the entire run for use in calculating the dead time correction given by eq. (5). Since the number of start pulses is so critical in making the dead time correction, a test is made every second to insure that the proper number of starts is being recorded. If the correct number is not being recorded, the computer automatically terminates the run. The start signal also initiates several delayed gate generators, which are used to examine various time portions of the neutron spectrum.



In order to reduce time slewing due to the finite rise time of the phototube pulse, the anode signals are fed to zero crossing discriminators. [10] The output of each of the cross overs is split, with one output signal going to a "STROBED COINCIDENCE" circuit. The common input ("Strobe") to this circuit is the signal from a delayed gate generator set to open between linac beam pulses. This allows the phototube noise rate to be measured between pulses. This rate is an indication of phototube stability. [11] Every five seconds, the computer tests to insure that the noise rate is within predetermined limits. If it is not, the computer automatically terminates the run and informs the experimenter. The other output of the zero crossing discriminators goes to a 2-out-of-3 AND GATE [12] which is used to eliminate phototube noise signals between the three phototubes. The output of the 2-out-of-3 AND GATE is also split, with one output signal going to the remainder of the conventional fast stop electronics. (A more detailed description of the electronics is in preparation for publication.) The other output of the 2-out-of-3 AND GATE is recorded for one second. The computer then tests whether the number of counts is greater than some lower limit. If the limit is not exceeded, it indicates that one of the zero crossing discriminators has failed, and again the computer automatically terminates the run and informs the experimenter.

The signal out of the stop electronics is also split. Part of the stop signal is gated with the signal from a delay gate generator set to allow neutrons with energies between 500 keV and 15 MeV to be recorded by the TIM. If no stop signal was detected during the period of the delayed gate, an artificial marker pulse is used to stop the TIM, and reset it for the next machine pulse. The other part of the stop signal is counted and used in the 20 minute ratios of the electron beam monitors previously mentioned.

In addition to the first order dead time correction mentioned earlier, a second order correction may be necessary if the linac beam current varies. To minimize this correction, a dual trip meter, driven by the P2 integrator, has its limits set so that when the beam current is not within  $\pm 10\%$  of the average, a signal is sent which will turn off the Group Enable. When it is necessary to correct for this second order dead time, the output of the P2 integrator, recorded for 5 second intervals, is used to form a profile of linac beam current distribution during the run.

At the end of a run all of the experimental information is punched onto paper tape. This is then transferred to magnetic tape using another SDS-920 computer. The magnetic tape is then used by the Univac 1108 at NBS to make dead time corrections on each run; combine all of the sample-in runs, sample-out runs, and background runs; normalize the total beam charge for the sample in, and sample out runs; subtract properly normalized background; and for each channel, calculate the transmission, the total cross section, the statistical error on the cross section, and the neutron energy. The final form of data is available as a listing, on cards, or as a plot.

#### 4. Conclusion

This paper has shown the versatility of an on-line computer for doing Nuclear Physics research by giving a detailed explanation of how the Neutron Time-of-Flight experiments use such a system.

The main features of the SDS-920 computer used on-line were given. The use of the interrupt capability of this computer for gathering data from experimental equipment was described. Board Programs and their initiation throughout the Program Selector Board were described as one method of manipulating the information in the data fields of Interrupt or Board programs.

For those not familiar with the Neutron Time-of-Flight program being carried out with the NBS linac, a description of the experimental arrangement was given. Included in this description was what signals the experimental apparatus supplied to the computer and how the computer was able to use information to determine if the monitors were within preset limits and if not to automatically terminate the run. By having the computer monitor the experimental conditions the experimenter is relieved of much of the routine data gathering and thereby is allowed to concentrate on the experiment itself.

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## Appendix A. Computer Programs

The appendix will explain how the computer performs some of the tests, how data is gathered and manipulated, etc., by actually describing the machine language programs<sup>2</sup> necessary for the on-line computer for gathering data in a total cross section measurement.

Figure 3 shows all of the signals sent to and from the computer during a typical measurement. (Indicated is the exact route of each signal, although this is not pertinent for the following description.) Signals sent to the computer terminate in one of the circles which indicate the priority level of the interrupt program used to process the signal. Interrupt programs which send signals are indicated by having the lines originate from one of the circles. The dotted lines originating from some of the interrupt programs indicate that the program from which the line originates needs information contained in the interrupt program data field on which the line terminates. The boxes labeled S. T. are shaping devices which allow the EOM signals to initiate other interrupt programs.

The machine language programs will be discussed in the same order as they appear in the Interrupt and Board Linkage Tables given in Tables 1 and 2. With the computer loaded in this manner, 15K out of the 16K memory cells are occupied. Two programs, however, (4100 Time Channels, IPIC, and 4100 Sequester, BPKM) occupy slightly over 8K of memory due to their 4K data fields. Most of the Interrupt programs are completed in times of the order of 30 to 260  $\mu$ s. The Interrupt program associated with the TIM, however, takes 800  $\mu$ s since it must do a decimal to binary conversion for each piece of information recorded in its data field. Since the Interrupt program associated with the PSB are lower priority than the data gathering Interrupt programs, the amount of time it takes to complete Board programs is not given.

Both in Interrupt and Board programs, the same program may serve several functions with only the quantity recorded in the data field being different. In this case, after the program has been described only the quantity recorded in the data field will be stated. Board programs may transmit data to the typewriter over one of two buffers termed W and Y. If the programs are the same except for the Buffer, they will be described only once. All programs are given four letter mnemonics, the first two being either BP for Board programs or IP for Interrupt programs. Hence only the last two letters of each mnemonic is given.

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<sup>2</sup> Complete documentation of all programs for the ROMEO system exist in the Linac Radiation Division Office at the Center for Radiation Research.



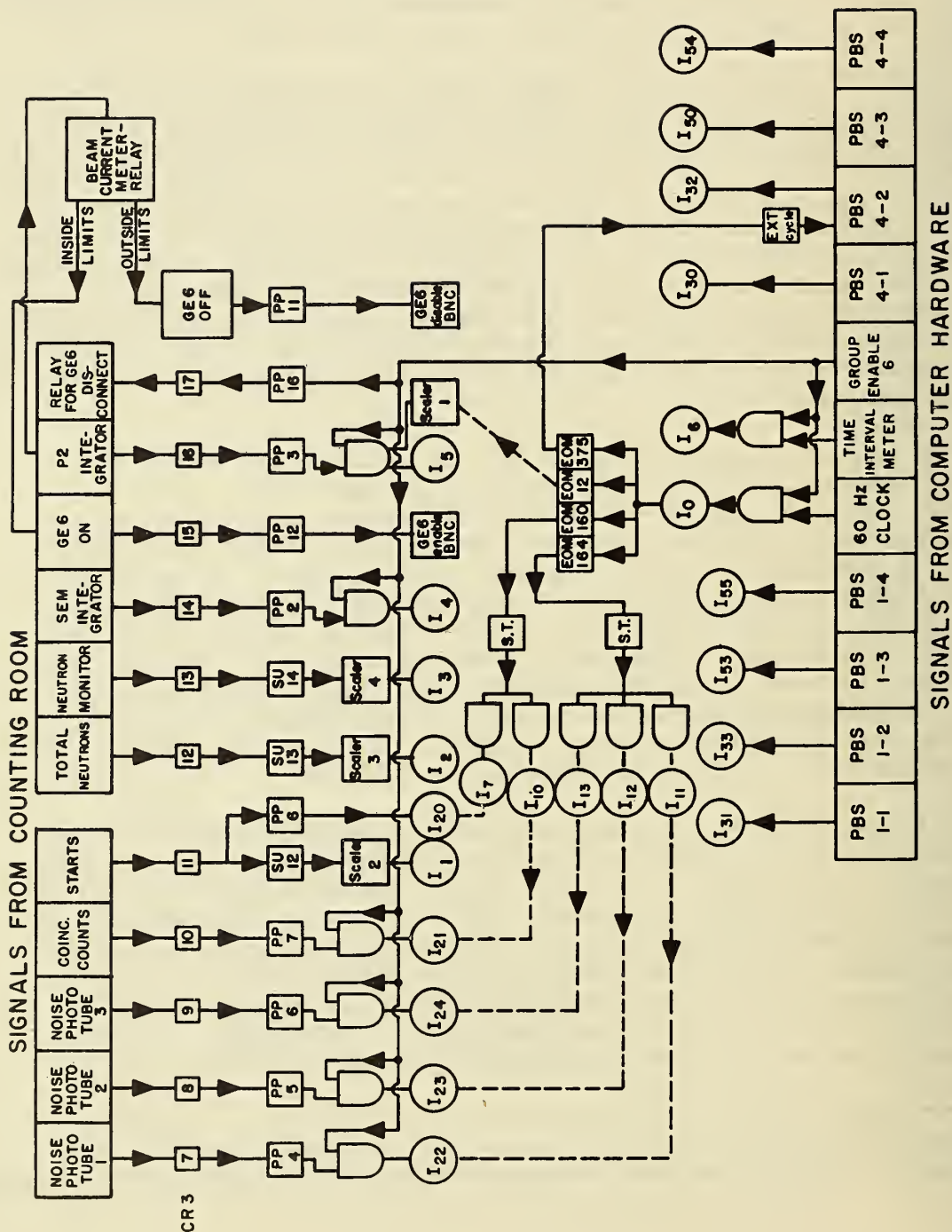


Figure 3. Signal source of all signals sent to the on-line computer. I indicates one of the 80 interrupt levels of the computer. See text for meaning of remaining symbols.



If it is necessary to refer to another program in the description of any program, the linkage location of the referenced program (prefixed) by IP for Interrupt and BP for Board programs) will be given.

## A. 1 Interrupt Programs

### 00 Master Timer (MT)

This program performs two functions. First, it records 60 hertz clock pulses during the time GE is on to determine if the proper amount of time has elapsed and the computer should monitor one of the experimental parameters. This monitoring is accomplished by the Master Timer Program sending an EOM signal which initiates the monitoring program after the Master Timer program is completed. The monitoring program interrogates the data field of the interrupt program actually recording the monitor output and then determines whether the monitor is within proper limits. Every second, the Master Timer Program emits an EOM 160 pulse initiating the programs Start Rate (IP07) and Coincidence Rate (IP10). Every 5 seconds an EOM 164 pulse initiates the programs Tube Noise-1 (IP11), Tube Noise-2 (IP12) and Tube Noise-3 (IP13). Every 20 minutes an EOM 347 pulse is sent initiating the "20 Minute Sequencer" (BP74). The second function of the Master Timer program is to use the first 64 words of the data field to form a profile of the short term linac beam stability. This is done by recording the contents of scaler 1 every 5 seconds, multiplying this number by 64 and dividing it by 500 (the maximum number of pulses from the P2 integrator in 5 seconds), and then using this as the channel address to increment by one.

### 01 Increment Data (RT)

This program increments its data field by one each time it is initiated. This is an example of one basic program which is used to record different experimental parameters. This particular increment data program records the number of times scaler 2 reached 4096 counts, i.e., the overflows from scaler 2. To insure that there is an interrupt program associated with every interrupt level, the increment data program is loaded at all otherwise unused levels. This prevents any spurious signal over an unused interrupt line from "hanging up" the computer.

### 02 Increment Data (RT)

See IP01. This program records scaler 3, "4096" counts.

### 03 Increment Data (RT)

See IP01. This program records scaler 4, "4096" counts.

#### 04 Increment Data (RT)

See IP01. This program records P2 integrator counts.

#### 05 Increment Data (RT)

See IP01. This program records SEM integrator counts.

#### 06 4100 Time Channels (IC)

This program brings the BCD word from the TIM into the computer memory and tests whether the number in its BCD form is greater than 4096. If the number is greater, the program exits, and if it is less, the number is converted to binary, and the appropriate word in the 4096 data field is incremented by one.

#### 07 Start Rate (SR)

This program sends out a warning if the proper number of start counts are not being detected. Every second, the Master Timer program (IP00) initiates the Start Rate program, which in turn reads the data field of IP20. If the number of counts read is less than the value in the first word of its data field, the program sends out signals to turn off the Group Enable, turns on light 375, and stores the number read in the second word in its data field. Independent of the value of the data word read, the program clears the first word of data of IP20.

#### 10 Coincidence Rate (SQ)

Every second this program monitors the number of coincidence counts from the stop detector. It is very similar to Start Rate (IP07) but with two exceptions: the data field read is IP21, and, if there is a failure (no coincidence counts detected) a pulse is sent to turn on light 376. IP21 counts the number of coincidence counts.

#### 11 Tube Noise-1 (TN)

This program monitors the noise rate in phototube No. 1 between machine pulses. It reads the data field of IP22. If the number read is not greater than the first word in its data field and smaller than the second word in its data field, signals are sent to turn off the Group Enable, turn on light 377, and finally store the number read in the third word of its data field. In all cases, the data field of IP22 is cleared. This program is initiated by the Master Timer Program (IP00) every 5 seconds. The numbers loaded into the first two words in the data field (this can be done with BP72) are usually the noise rate at the start of the experiment  $\pm 20\%$ .

12 Tube Noise-2 (TM)

See IP11. This program monitors the noise rate in phototube 2.  
The data field read is IP23.

13 Tube Noise-3 (TL)

See IP11. This program monitors the noise rate in phototube 3.  
The data field read is IP24.

20 Increment Data (RT)

See IP01. This program records the number of start pulses.

21 Increment Data (RT)

See IP01. This program records the number of coincidence counts.

22 Increment Data (RT)

See IP01. This program records phototube 1 noise pulses.

22 Increment Data (RT)

See IP01. This program records phototube 2 noise pulses.

24 Increment Data (RT)

See IP01. This program records phototube 3 noise pulses.

30 Program Selector Board 4-1 (HP)

This is the control program for the first set of thumbdials of the Program Selector Board in Counting Room 3. The remainder of the Selector Boards are given in their titles where 1- $\alpha$  and 4- $\alpha$  refer to the  $\alpha$ th set of thumbdials in the Control Room and Counting Room 3 respectively. See Section 2 for a further description of the PSB.

31 Program Selector Board 1-1 (HD)

See IP30.

32 Program Selector Board 4-2 (HQ)

See IP30..

33 Program Selector Board 1-2 (HE)

See IP30.

50 Program Selector Board 4-3 (HR)

See IP30.

53 Program Selector Board 1-3 (HF)

See IP30.

54 Program Selector Board 4-4 (HS)

See IP30.

117 Delete (HC)

This program can be used to delete any Interrupt or Board program from the computer memory, by pushing the DELETE button on the PSB board in the Control Room, and then typing:

IP0006, IP //.

where 0006 is the linkage location of the Interrupt program to be deleted. For Board programs, the IP is replaced with BP. After the program has been deleted, DUN will be typed.

#### A.2. Board Programs

If a Board Program uses dials 1-4 for controlling functions within the program, there will be an asterisk after the linkage location. These dials usually control the start location in a data field where some operation begins. Unless stated otherwise, the following convention will be followed: the first word of the data field corresponds to dials 1-4 equal to 0, second word to dials 1-4 equal to 1, etc., i.e., the number in dials 1-4 is the octal number less one of the start location. All Board Program mnemonics begin with BP

00\* Zero Word (IO)

This zeros the word in the object data field corresponding to dials 1-4.

01 Clear Data (LB)

Clears the entire object data field.

02\* Type Line of Data - Y-Buffer (YL)

This program types without sign, the contents of the data field as decimal integers. This program types the first 10 words of data in a single horizontal line, then the next 10, etc. Type out begins at the location given by dials 1-4. The program can be terminated at any time by setting SKS 1000 which is available



as a switch on the PSB.

04 Type 4 Carriage Returns - Y-Buffer (YE)

This program types 4 carriage returns on the typewriter connected to the Y buffer and exits.

05 General I7 Punch (RP)

This program will punch the object data field in a FORTRAN compatible mode, I7. It will also read tapes made using a Fortran program punched in a I7 format. If Breakpoint 2 is reset, this program will punch tape, and if it is set, it will read paper tape. When reading paper tape, the program assumes that the first word is the number of words to be read. After each word is punched/read a test is made to see if Breakpoint 1 is set. If it is set, the program exits.

07 Paper Taper (RA)

This program will punch on paper tape the object data field in a binary form. If Breakpoint 2 is reset, the program will punch tape, and if it is set it will read tape. Either of these operations can be terminated by setting Breakpoint 1.

10 Type Data Message - W-Buffer (IO)

This program will type out the contents of the object data field in a form such that each word in the data field is treated as if it consisted of four typewriter characters. The object data field can be loaded in this form with the Load Data Field Program (BP16). The message is typed from the typewriter connected to the W-Buffer.

11 Type Data Message - Y-Buffer (YD)

Same as BP10 for Y-Buffer.

12\* Type Line of Data-W-Buffer (TL)

See BP02.

13 List Sequencer (TW)

This program types the contents of the data field as if each word in the data field corresponded to the ten dials on a PSB.

14 Decimal Type In (IO)

This program will enter decimal integers into the object field by means of the typewriter. The location into which the decimal

data is to be typed is given by

\*10.

followed by a carriage return. Then the decimal integer is typed

9999.

followed by a carriage return. If another number is typed, it will be loaded into the next location in the data field. The program is exited by typing a control character such as a space.

#### 15 Store Message (IE)

This is a dummy program which has a data field into which a message of 80 typewriter characters can be loaded. The Type Data Message Programs (BP10 and BP11) operate on this data field.

#### 16 Load Data Field (IC)

This program will enter typewriter characters into the object data field until the data field is completely filled. This program can be used to load a message into the Store Message Program (BP15). In loading the message, first a carriage return should be typed, then the message typed (including spaces to fill up 78 characters), and finally, another carriage return is typed.

#### 22 Paper Tiger (RT)

This program can be used to make a new Master Tape of the contents of the computer memory. The program first punches a self-loading bootstrap. Then, all memory cells in the computer, through the first unused cell, are punched.

#### 24 Scope - Control Room (SA)

This program presents a CRT display of the object data field on the oscilloscope in the control room.

#### 25 Sum (CZ)

This program sums the contents of the object data field and stores the result in its data field.

## 26 One Word Sequester (K0)

This program will copy the first word of the object data field into its data field. The Ratio Program (BP40) can only operate on the data field of Board programs, so it is necessary to temporarily store the data field of an Interrupt Program before it can be used for a ratio. This program provides temporary storage for the counts recorded in scaler 3.

## 27 One Word Sequester (K0)

See BP26. This program, provides temporary storage for the counts recorded in scaler 4.

## 30 Ratio Loader (CX)

This program will copy its two word data field into the first two words of the object data field. Since the Ratio program (BP40) requires that its data field be loaded with the linkage location of the programs whose ratio is to be taken, this much shorter program can be used to load the data field of the Ratio program just before its execution. Stored in this program's data field are the linkage locations of the programs for the ratio of SEM counts to P2 counts for each 20 minute ratio.

## 31 Ratio Loader (CX)

See BP30. This program is for the 20 minute ratio of total neutron counts to P2 counts.

## 32 Ratio Loader (CX)

See BP30. This program is for the 20 minute ratio of total neutron counts to neutron monitor counts.

## 33 Ratio Loader (CX)

Same as BP30 but for entire run.

## 34 Ratio Loader (CX)

Same as BP31 but for entire run.

## 35 Ratio Loader (CX)

Same as BP32 but for entire run.

## 36 Scaler Save (IA)

This program reads the first word of the object data field, then adds the number to its data field. This program is necessary to

preserve the sum of the counts accumulated in the scalers, since the EOM pulse which reads the scaler residuals also clears the scalers. This particular Scaler Save program records the number of P2 counts.

37 Scaler Save (IA)

See BP36. This program records the total number of SEM counts.

40 Ratio-Y-Buffer (RG)

This program types the ratio of non-zero numbers, truncating the result to three significant figures. If one of the numbers is zero, the program types ERROR and exits. The linkage location of the Board Program whose data field is to be the numerator, is loaded into the first word of data of the Ratio program. The second word of data of the Ratio Program is loaded with the linkage location of the Board Program whose data field is to be the denominator. The form of the result typed out is

$$6543210/3271605 = 200.*E-2$$

This program will work only with Board programs. If the ratio of data in an Interrupt program is desired, this data must be temporarily stored in a Board program. The program types the ratio over the teletype connected to the Y-Buffer.

46 Scaler Save (IA)

See BP36. This program records the total number of counts in scaler 3.

47 Scaler Save (IA)

See BP36. This program records the total number of counts in scaler 4.

50 Read Scaler Residuals - Scaler 2 (QB)

This program reads the residual counts in scaler No. 2. It adds to this number, the number of times scaler No. 2 reached 4096 (i.e., scaler 2 overflows).

51 Read Scaler Residuals - Scaler 3 (QC)

See BP50. This program reads the residual counts in scaler 3. The answer is multiplied by 8, as the program assumes that the input to scaler 3 is a prescaler with a scale of 8.



52 Read Scaler Residuals - Scaler 4 (QD)

See BP50. This program reads the residual counts in scaler 4.

53 Clear Scalers 2, 3, 4 (EU)

This program clears the contents of scalers 2, 3, and 4.

54\* List Collector (LX)

This program will collect words out of the object data field and store them sequentially in its data field. Dials 3, 4 give the number of words of the object data field to be transferred. To start loading at the first word of the data field of the list collector, set dial 1 to 1.

55 Run Number Increment (NR)

This program adds one to its data field each time it is initiated.

56 Group Enable 6 On (ON)

This program turns on Group Enable 6.

57 Group Enable 6 OFF (OF).

This program turns off Group Enable 6.

60 Scope - Counting Room 3 (SD)

See BP50. For counting Room 3.

61\* Simple Operation (MB)

This program will perform operations on the object data field depending on the value of dials 1-4, and then store the results in its 64 word data field.

| Dial 1, 2 | Dial 3, 4 | Function   |
|-----------|-----------|--|
| 00        |           | sequester $a_{oi} \rightarrow a_{si}$                                |
| 01        |           | accumulate $a_{oi} + a_{si} \rightarrow a_{si}$                      |
| 02        |           | subtract object<br>from subject $a_{si} - a_{oi} \rightarrow a_{si}$ |
| 03        |           | subtract subject<br>from object $a_{oi} - a_{si} \rightarrow a_{si}$ |
| 04        |           | first difference $a_{oi+1} - a_{oi} \rightarrow a_{si}$              |

|    |   |                             |  |
|----|---|-----------------------------|--|
| 05 |   | running sum                 | $\sum_{i=1}^j a_{oi} \rightarrow a_{sj}$ |
| 06 |   | set object data<br>to zero  | $a_{oi} \rightarrow 0$                   |
| 07 |   | set subject data<br>to zero | $a_{si} \rightarrow 0$                   |
| 10 | k | add constant                | $a_{oi} + k \rightarrow a_{si}$          |
| 11 | k | subtract constant           | $a_{oi} - k \rightarrow a_{si}$          |
| 12 | k | multiply constant           | $a_{oi} * k \rightarrow a_{si}$          |

#### 62\* Simple Operation (MD)

See BP61. This program is a simple operation program with a 256 word data field.

#### 63\* Smooth (LI)

This program calculates  $\sum_{i=2}^{N-1} (C_{i-1} + 2*C_i + C_{i+1})/4$  for each channel i.

Here,  $C_i$  is the number of counts in channel i and N is the number of channels. The number of times the data is smoothed is one more than the octal number in dials 1-4.

#### 64 4100 Sequester (KM)

This program will provide temporary storage for the TIM data field by transferring the TIM data to its data field.

#### 65\* 256 Block Sequester (KN)

This program is designed to be used with the 4100 Sequencer (BP64) or 4100 Time Channels (IP06) programs. This program will transfer 256 word blocks of data from the object data field to its data field. Which 256 word block of data is transferred is determined by dials 1, 2 and is given below:

| <u>Dials 1, 2</u> | <u>Channels</u> | <u>Energy (MeV)</u> | <u>Dials 1, 2</u> | <u>Channels</u> | <u>Energy (MeV)</u> |
|-------------------|-----------------|---------------------|-------------------|-----------------|---------------------|
| 00                | 1-256           |                     | 10                | 2049-2304       | 1.94-1.54           |
| 01                | 257-512         | 130-30.1            | 11                | 2305-2560       | 1.54-1.25           |
| 02                | 513-768         | 30.1-13.9           | 12                | 2561-2816       | 1.25-1.04           |
| 03                | 769-1024        | 13.8-7.65           | 13                | 2817-3072       | 1.04-.871           |
| 04                | 1025-1280       | 7.64-4.93           | 14                | 3073-3328       | .870-.744           |
| 05                | 1281-1536       | 4.92-3.44           | 15                | 3329-3584       | .743-.642           |
| 06                | 1537-1792       | 3.43-2.53           | 16                | 3585-3840       | .641-.589           |
| 07                | 1793-2048       | 2.52-1.95           | 17                | 3841-4096       | .588-.495           |

66 One Word Sequester (K0)

See BP26. This program provides temporary storage for the counts recorded by scaler 3.

67 One Word Sequester (K0)

See BP 26. This program provides temporary storage for the counts recorded by scaler 4.

71\* List Loader (HD)

This program reads the dials on the top board in the Control Room. It stores this number in the object data field given by one more than the octal number in dials 1-4. This program can be used to load the data field of the Sequencer Program.

72\* List Loader (HP)

See BP71. This program reads the dials on the top board in Counting Room 3.

73\* Sequencer (HF)

Initiating this single program allows a sequence of Board programs to be carried out. This is accomplished by loading successive words in the data field of the Sequencer Program which have the PSB dial configuration of the desired programs. The Sequencer program will execute successively the contents of its data field treated as Selector Board calls until a zero word is encountered, or the end of the data field is reached. The Sequencer program may be initiated at any place in the sequence by setting dials 3 and 4 to one less than the desired starting location. Some care must be taken in the use of this program, as it carries out successive programs by modifying the Program Selector Board interrupt program and restoring it upon leaving. If for any reason, the Sequencer program does not go to completion, the PSB control program will be destroyed. It must be deleted and reloaded before any calls can be made from the board. The Sequencer program uses as its object program, the interrupt program for the PSB. This Sequencer program has a  $40_8$  word data field and will only operate from Selector Board position 1-4.

74\* Sequencer (HK)

This program is the "20 Minute Sequencer Program" given in Table 3. It is similar to the Sequencer (BP73) program except that it has a  $77_8$  word data field and operates from Selector Board Position 4-2.

Table 3

## 20 Minute Sequencer

|   | PBS  | Thumbdials |
|---|------|------------|
| 00 Group Enable 6 Off                                   |      | 57         |
| 01 Read Scaler Residuals - Scaler 3                     | 1002 | 51         |
| 02 Read Scaler Residuals - Scaler 4                     | 1003 | 52         |
| 03 One Word Sequester - Scaler 3                        | 51   | 26         |
| 04 One Word Sequester - Scaler 4                        | 52   | 27         |
| 05 One Word Sequester - P2                              | 1004 | 66         |
| 06 One Word Sequester - SEM                             | 1005 | 67         |
| 07 Scaler Save - Scaler 3                               | 51   | 46         |
| 10 Scaler Save - Scaler 4                               | 52   | 47         |
| 11 Scaler Save - P2                                     | 1004 | 36         |
| 12 Scaler Save - SEM                                    | 1005 | 37         |
| 13 Clear Scaler "Units" - Scaler 3                      | 1002 | 01         |
| 14 Clear Scaler "Units" - Scaler 4                      | 1003 | 01         |
| 15 Group Enable 6 on                                    |      | 56         |
| 16 Load Ratio (SEM/P2 - short run)                      | 40   | 30         |
| 17 Ratio  |      | 40         |
| 20 Load Ratio (total neutron/P2-short run)              | 40   | 31         |
| 21 Ratio  |      | 40         |
| 22 Load Ratio (total neutron/neutron monitor-short run) | 40   | 32         |
| 23 Ratio  |      | 40         |
| 24 Type Carriage Return-Y-Buffer                        |      | 04         |
|   |      |            |
| 60 Group Enable 6 Off                                   |      | 57         |
| 61 Clear Scaler 2,3,4                                   |      | 53         |
| 62 Clear Beam Profile Data                              | 1000 | 01         |
| 63 Clear Scaler "units" - scaler 2                      | 1001 | 01         |
| 64 Clear Scaler "units" - scaler 3                      | 1002 | 01         |
| 65 Clear Scaler "units" - scaler 4                      | 1003 | 01         |
| 66 Clear P2 counts                                      | 1004 | 01         |
| 67 Clear SEM counts                                     | 1005 | 01         |
| 70 Clear TIM Data                                       | 1006 | 01         |
| 71 Clear scaler Save - Scaler 3                         | 46   | 01         |
| 72 Clear Scaler Save - Scaler 4                         | 47   | 01         |
| 73 Clear Scaler Save -P2                                | 36   | 01         |
| 74 Clear Scaler Save - SEM                              | 37   | 01         |



75\* Sequencer (HR)

See BP74. This program is the "Final Sequencer Program," given in Table 4, and operates only from Selector Board Position 4-4.

76 Linkage Lister (HC)

This program gives a listing of the Interrupt and Board Linkage tables at the time the program is initiated.

77 Loader (HA)

This is the program used to load individual machine language programs from paper tape into the computer. The command to load the tape is given from the typewriter and is of the form

IP0006, IPIC.

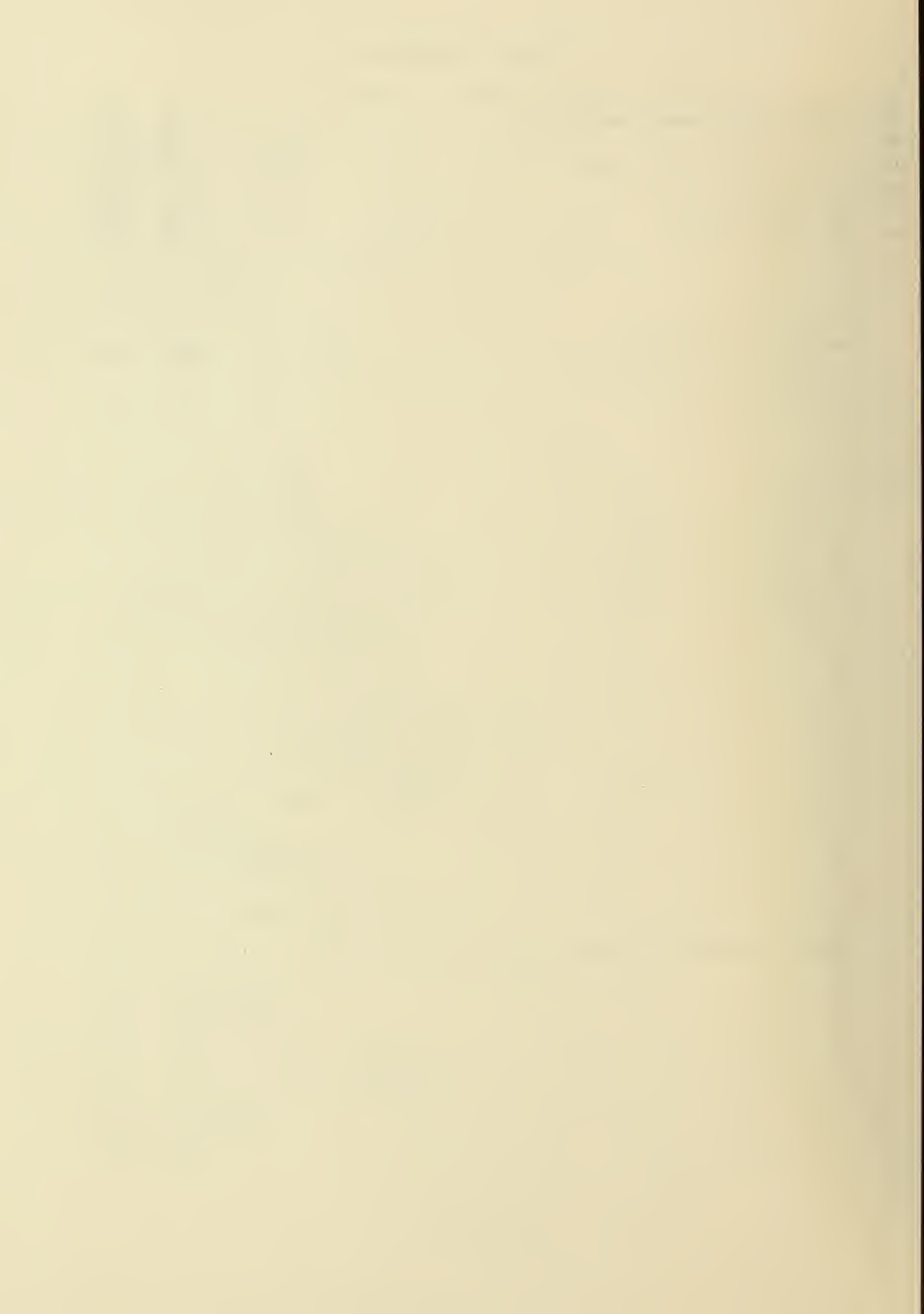
In this example, Interrupt program IPIC is being loaded into interrupt location 06. For Board programs the I is a B. After the period is typed, the photoreader will read the tape. When the program has been successfully loaded, DUN will be typed. To exit from the program, set Breakpoint 1 and type a space.

Table 4

| Final Sequencer |  |    |    | PBS Thumbdials |    |
|-----------------|--|----|----|----------------|----|
| 00              | Transfer to temporary storage - data           |    |    | 1006           | 64 |
| 01              | Transfer to temporary storage - beam profile   |    |    | 1000           | 61 |
| 02              | Read Scaler Residuals - Scaler 2               |    |    | 1001           | 50 |
| 03              | Read Scaler Residuals - Scaler 3               |    |    | 1002           | 51 |
| 04              | Read Scaler Residuals - Scaler 4               |    |    | 1003           | 52 |
| 05              | One Word Sequester - Scaler 3                  |    |    | 51             | 26 |
| 06              | One Word Sequester - Scaler 4                  |    |    | 52             | 27 |
| 07              | One Word Sequester - P2                        |    |    | 1004           | 66 |
| 10              | One Word Sequester - SEM                       |    |    | 1005           | 67 |
| 11              | Scaler Save - Scaler 3                         |    |    | 51             | 46 |
| 12              | Scaler Save - Scaler 4                         |    |    | 52             | 47 |
| 13              | Scaler Save - P2                               |    |    | 1004           | 36 |
| 14              | Scaler Save - SEM                              |    |    | 1005           | 37 |
| 15              | Sum Data                                       |    |    | 1006           | 25 |
| 16              | Increment Run Number                           |    |    |                | 55 |
| 17              | Accumulate Run Number                          | 10 | 01 | 55             | 54 |
| 20              | Accumulate P2 Counts                           |    | 01 | 36             | 54 |
| 21              | Accumulate SEM Counts                          |    | 01 | 37             | 54 |
| 22              | Accumulate Start Counts                        |    | 01 | 50             | 54 |
| 23              | Accumulate Neutron Monitor Counts              |    | 01 | 47             | 54 |
| 24              | Accumulate Total Neutron Counts                |    | 01 | 46             | 54 |
| 25              | Accumulate Analyzer Sum                        |    | 01 | 25             | 54 |
| 26              | Type Carriage Returns-Y-Buffer                 |    |    |                | 04 |
| 27              | Load Ratio (SEM/P2-short run)                  |    |    | 40             | 30 |
| 30              | Ratio  |    |    |                | 40 |
| 31              | Load Ratio (total neutron/P2-short run)        |    |    |                | 31 |
| 32              | Ratio  |    |    |                | 40 |
| 33              | Load Ratio (total neutron/neutron-short run)   |    |    |                | 32 |
| 34              | Ratio  |    |    |                | 40 |
| 35              | Type Carriage Returns - Y-Buffer               |    |    |                | 04 |
| 36              | Type Heading                                   |    |    |                | 11 |
| 37              | Type Line of Data                              |    |    |                | 02 |
| 40              | Load Ratio (SEM/P2-sum)                        |    |    |                | 33 |
| 41              | Ratio  |    |    |                | 40 |
| 42              | Load Ratio (total neutron/P2-sum)              |    |    |                | 34 |
| 43              | Ratio  |    |    |                | 40 |
| 44              | Load Ratio (total neutron/neutron monitor-sum) |    |    |                | 35 |
| 45              | Ratio  |    |    |                | 40 |
| 46              | Punch "Summed Data"                            |    |    | 54             | 05 |
| 47              | Clear Beam Profile                             |    |    | 1000           | 01 |
| 50              | Clear Scaler "units" - scaler 2                |    |    | 1001           | 01 |
| 51              | Clear Scaler "units" - scaler 3                |    |    | 1002           | 01 |
| 52              | Clear Scaler "units" - scaler 4                |    |    | 1003           | 01 |
| 53              | Clear P2 counts                                |    |    | 1004           | 01 |
| 54              | Clear SEM counts                               |    |    | 1005           | 01 |
| 55              | Clear Data                                     |    |    | 1006           | 01 |

Table 4 (continued)

|    |                              |      |    |
|----|------------------------------|------|----|
| 56 | Clear Scaler Save - scaler 3 | 46   | 01 |
| 57 | Clear Scaler Save - Scaler 4 | 47   | 01 |
| 60 | Clear Scaler Save - P2       | 36   | 01 |
| 61 | Clear Scaler Save - SEM      | 37   | 01 |
| 62 | Clear Scaler 2, 3, 4         |      | 53 |
| 63 | Punch TIM Data               | 64   | 05 |
| 64 | Punch Beam Profile           | 61   | 05 |
| 65 |                              |      |    |
| 66 |                              |      |    |
| 67 |                              |      |    |
| 70 | Scope display of data        | 1006 | 60 |
| 71 |                              |      |    |
| 72 |                              |      |    |
| 73 |                              |      |    |
| 74 |                              |      |    |
| 75 |                              |      |    |
| 76 |                              |      |    |
| 77 |                              |      |    |





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